

Muon $g - 2$ in GMSB with Adjoint Messengers

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Abstract

We explored the sparticle mass spectrum in light of the muon $g - 2$ anomaly and the little hierarchy problem in a class of gauge mediated supersymmetry breaking model. Here the messenger fields transform in the adjoint representation of the Standard Model gauge symmetry. To avoid unacceptably light right-handed slepton masses the standard model is supplemented by additional $U(1)_{B-L}$ gauge symmetry. Considering a non-zero $U(1)_{B-L}$ D-term leads to an additional contribution to the soft supersymmetry breaking mass terms which makes the right-handed slepton masses compatible with the current experimental bounds. We show that in the framework of $\Lambda_3 < 0$ and $\mu < 0$, the muon $g - 2$ anomaly and the observed 125 GeV Higgs boson mass can be simultaneously accommodated. The slepton masses in this case are predicted to lie in the few hundred GeV range, which can be tested at LHC. Despite the heavy colored spectrum the little hierarchy problem in this model can be ameliorated and electroweak fine tuning parameter can be as low as 10 or so.

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1 Introduction

Even though minimal supersymmetric Standard Model (MSSM) can still be fit consistently with the current experimental results, the discovery of the Higgs boson with a mass ~ 125 GeV [1, 2] and absence of signal of the supersymmetric particles [3] at LHC bring severe constraints on the sparticle mass spectrum. It require rather heavy sparticles. Such a heavy mass spectrum for the sparticles leads to the question of the little hierarchy problem [4]. In the models with gauge mediated supersymmetry breaking (GMSB) [5, 6] the little hierarchy problem becomes more severe compare to the the gravity mediation supersymmetry breaking scenario [7]. In general, the trilinear SSB A-terms in GMSB scenarios are relatively small at the messenger scale, even if an additional sector is added to generate the $\mu/B\mu$ terms [8]. Because of the small A-terms, accommodating the light CP-even Higgs boson mass around 125 GeV requires a stop mass in the multi-TeV range [9]. While a large trilinear SSB terms allows relatively light stop quark solutions in gravity mediation supersymmetry breaking scenario to be consistent with the Higgs boson mass constraint [10]. On the other hand, a multi-TeV top squark has a very strong influence on the sparticle spectrum [9], if we assume that the messenger fields reside in the $SU(5)$ representations such as $5 + \bar{5}$ or $10 + \bar{10}$. This case is called minimal GMSB scenario, since it is the simplest scenario that preserves gauge coupling unification of the minimal supersymmetric standard model (MSSM) and provides non-zero SSB mass terms for all supersymmetric particles. It is often assumed that all messenger fields have a universal mass in this simplest model. Even if one assumes a large mass splitting among the colored and non-colored messenger fields, the sparticle mass spectrum cannot be entirely separated, since all fields from $5 + \bar{5}$ (or $10 + \bar{10}$) representation have non-zero hypercharge, and they can generate non-zero masses through hypercharge interactions. This means that in these models the maximal splitting among sfermion SSB mass terms cannot exceed the ratio of corresponding fermion hypercharges. Therefore, the colored and non colored sparticle mass spectra are closely linked here. For instance, if we have a multi-TeV mass top squark in the minimal GMSB scenario, then the whole SUSY sparticle spectrum is also around the TeV scale [9]. Note that t - b - τ Yukawa coupling unification can be realized in these models and it provides a specific spectrum for sparticle masses [11] which tested at future experiments.

It was shown a while ago that a GMSB model could be realized having the messenger fields in the adjoint representations of $SU(3)_C$ and $SU(2)_L$ [12], we call this scenario as GMSB-Adj. The messenger fields in these representations do not carry any hypercharge, and hence there is no common SSB terms generated for the colored and non-colored sectors. Thus, one can have a light mass spectrum for the left handed sleptons, while the stops and othe colored particles still can have multi-TeV masses. Indeed, this model suffers from inconsistently light right handed sleptons. Since in this scenario messenger fields does not have hypercharge as the result the right-handed sleptons are generated at high loop level at the M_{mess} scale and is negligible compare othes sfermion masses. As we know slepton mass can increase through RGE evaluation. But there is no enough contribution from the RGE flaw to realize sleptons heavier than about 100 GeV at the low scale. To overcome this problem, one can consider non-zero D-term contributions [13] which generate SSB mass term for the right-handed sleptons at M_{mess} . A detailed analyses have been performed in a recent study [13], and it has been shown that a consistent slepton spectrum can be realized when a non-zero $U(1)_{B-L}$ D-term contribution is consider around the messenger scale. In this set up, the stops are still heavier than about 2 TeV, while the all slepton are rather

light, 100 GeV or so.

Besides the right handed sleptons in the GMSB-Adj scenario bino also does not obtain SSB mass term at one loop level. But RGE evaluation make bino mass in the $O(\text{GeV})$ – $100(\text{GeV})$ interval. On the other hand there is not severe constraint for bino mass from the experiment. For instance existence of a near massless bino, however, would contribute to $\Delta N_{eff} = N_{eff} - N_{eff,SM}$. The reason for this is that the essentially massless bino decouples from the thermal background around the same time as the neutrinos. The decoupling temperature also depends on the slepton mass which we take around the weak scale. However, if the slepton mass increases, the decoupling temperature also increases, e.g., if the slepton mass is 10 TeV, then the decoupling temperature will be $O(\text{GeV})$. The BICEP2 data [14] requires a larger $\Delta N_{eff}(=0.81 \pm 0.25)$ in order to reconcile with the Planck data [15]. Future data hopefully will settle this issue.

It is interesting to note that GMSB-Adj scenario [13] there are parameters space where the little hierarchy problem is ameliorated. Particularly it was found in ref. [13] that electroweak fine-tuning measure Δ_{EW} can be as low as $\Delta_{EW} \gtrsim 50$. Detailed discussion about Δ_{EW} see in [16] and references therein.

A light slepton spectrum is also favored, since it yields significant contributions to the muon anomalous magnetic moment (here after muon $g-2$). However, as shown in Ref. [13], it is not possible to resolve the muon $g-2$ problem in GMSB-Adj when it was consider $\Lambda_3 > 0$ and $\mu > 0$. There reason is that starting with tne mass for bino at the messenger scale the RGE evaluation leads to negative value for bino mass at the electroweak scale. On the other hand the contributions from the sparticles to muon $g-2$ is proportional to the combination of μM_i , where $i = 1, 2$ represent masses of the gauginos of $U(1)_Y$ and $SU(2)_L$ respectively. A light Bino along with light sleptons significantly contribute to muon $g-2$, but having bino in the model with negative sign [13] turns such contributions to be destructive in muon $g-2$ calculation. Even though M_2 provides contributions enhancing muon $g-2$, they are not enough to suppress those from the bino loop [13].

In this paper we continue investigation of model presented in Ref. [13]. Here we consider the parameter space when $\Lambda_3 < 0$ and $\mu < 0$. It leads to have at low scale $M_i < 0$ and $\mu < 0$ while $\mu M_i > 0$. So, as we will show in this case there is no negative contribution to the muon $g-2$ from bino and/or wino loop. We also consider electro week fine-tuning for this scenario. The outline of the paper is as follows: We briefly discuss the essential features of the model and the situation of muon $g-2$ in Section 2. After we summarize our scanning procedure and the experimental constraints imposed in our analyses in Section 3, we present our results in Section 4. Finally we summarize and conclude our results in Section 5.

2 The GMSB-Adj model

We summarize the essential features of GMSB-Adj in this section. A detailed description is given in Refs. [12]. In GMSB models, SUSY is broken in a hidden sector with a singlet field S through the following superpotential

$$W \supset (m_3 + \lambda_3 S)\text{Tr}(\Sigma_3^2) + (m_8 + \lambda_8 S)\text{Tr}(\Sigma_8^2). \quad (1)$$

where m_3 and m_8 are the messenger scales relevant to triplet and octet messengers denoted with Σ_3 and Σ_8 respectively. For simplicity it can be assume that $m_3 = m_8 = M_{\text{mess}}$. The

S field breaks SUSY when its F_S component develops a non-zero vacuum expectation value (VEV) denoted as $\langle F_S \rangle$. This VEV generates a mass splitting between bosonic and fermionic components of the messenger superfields as follows:

$$m_{b_i} = M_{\text{mess}} \sqrt{1 \pm \frac{\Lambda_i}{M_{\text{mess}}}} , \quad m_{f_i} = M_{\text{mess}} \quad (2)$$

where m_{b_i} and m_{f_i} with $i = 3, 8$ represent the bosonic and the fermionic components of Σ_3 and Σ_8 respectively. The mass difference between the bosons and fermions are expressed in terms of Λ_i , where $\Lambda_3 = \lambda_3 \langle F_S \rangle / M_{\text{mess}}$ and $\Lambda_8 = \lambda_8 \langle F_S \rangle / M_{\text{mess}}$. The messenger fields Σ_3 and Σ_8 decouple at M_{mess} and generate SSB mass terms. These mass terms are generated at one-loop for the gauginos as

$$M_1 = 0 , \quad M_2 \simeq \frac{g_2^2}{16\pi^2} 2\Lambda_3 \quad M_3 \simeq \frac{g_3^2}{16\pi^2} 3\Lambda_8 , \quad (3)$$

where M_i with $i = 1, 2, 3$ stand for gauginos associated with $U(1)_Y$, $SU(2)_L$, and $SU(3)_C$ respectively. $\Lambda_3 = \lambda_3 \langle F_S \rangle / M_{\text{mess}}$, and similarly $\Lambda_8 = \lambda_8 \langle F_S \rangle / M_{\text{mess}}$. Although the bino mass vanishes at the messenger scale, it is generated below the messenger scale through the RGE evolution [17]. The dominant contribution to the bino mass has the following form:

$$(16\pi^2)^2 \frac{d}{dt} M_1 = 2g_1^2 \left(\frac{27}{5} g_2^2 M_2 + \frac{88}{5} g_3 M_3 \right) + \frac{26}{5} y_t A_t. \quad (4)$$

The scalar SSB masses are generated at two loops and for GMSB-Adj case we have [12]

$$\begin{aligned} m_{\tilde{Q}}^2 &\simeq \frac{2}{(16\pi^2)^2} \left[\frac{4}{3} g_3^4 3\Lambda_8^2 + \frac{3}{4} g_2^4 2\Lambda_3^2 \right] \\ m_{\tilde{U}}^2 = m_{\tilde{D}}^2 &\simeq \frac{2}{(16\pi^2)^2} \left[\frac{4}{3} g_3^4 3\Lambda_8^2 \right] \\ m_L^2 &\simeq \frac{2}{(16\pi^2)^2} \left[\frac{3}{4} g_2^4 2\Lambda_3^2 \right] \\ m_{H_u}^2 = m_{H_d}^2 &= m_L^2 \\ m_E^2 &= 0 . \end{aligned} \quad (5)$$

where we have used the standard notation for the MSSM fields.

The right-handed slepton masses will be generated at a higher loop level, and thus, they vanish at the messenger scale. However, they are generated below the messenger scale from the RGE evolution. On the other hand, experimental constraints require that the sleptons must be heavier than 100 GeV or so. In order to generate right-handed slepton masses of order 100 GeV or heavier through RGE flow, some of the other sparticles should be around 100 TeV or so, which makes supersymmetry much less motivated for solving the gauge hierarchy problem.

To avoid this problem it was proposed to consider an extension of the SM gauge symmetry with $U(1)_{B-L}$, which is one of the most natural extension of the SM gauge symmetry. We assume that the $U(1)_{B-L}$ symmetry is spontaneously broken not far below the messenger scale. Thus, below the messenger scale the RGE evolution is the one associated

with the MSSM. It is very natural to consider non-zero D-term contribution [18] to the MSSM scalar SSB mass term. In this case we have

$$m_\phi^2 = (m_\phi^2)_{\text{GMSB-Adj}} + (e_{B-L}D)^2 \quad (6)$$

where ϕ represents the scalars and $(m_\phi^2)_{\text{GMSB-Adj}}$ is their masses generated by the messenger scales as given in Eq.(5). D stands for non-zero D-term contributions, and e_{B-L} denotes the $B - L$ charge of the field.

3 Scanning Procedure and Experimental Constraints

For our scan over the fundamental parameter space of GMSB with the adjoint messengers, we employed ISAJET 7.84 package [19] supplied with appropriate boundary conditions at M_{Mess} . In this package, the weak-scale values of gauge and Yukawa couplings are evolved from M_Z to M_{Mess} via the MSSM RGEs in the \overline{DR} regularization scheme. For simplicity, we do not include the Dirac neutrino Yukawa coupling in the RGEs, whose contribution is expected to be small.

The SSB terms are induced at the messenger scale and we set them according to Eqs. (3) and (5). From M_{Mess} the SSB parameters, along with the gauge and Yukawa couplings, are evolved down to the weak scale M_Z . In the evolution of Yukawa couplings the SUSY threshold corrections [20] are taken into account at the common scale $M_{\text{SUSY}} = \sqrt{m_{\tilde{t}_L} m_{\tilde{t}_R}}$, where $m_{\tilde{t}_L}$ and $m_{\tilde{t}_R}$ are the soft masses of the third generation left and right-handed top squarks respectively.

We have performed random scans over the model parameters in the following range:

$$\begin{aligned} -10^7 &\leq \Lambda_3 \leq 10^3 \text{ GeV} \\ 10^3 &\leq \Lambda_8 \leq 10^7 \text{ GeV} \\ 10^3 &\leq M_{\text{Mess}} \leq 10^{16} \text{ GeV} \\ 0 &\leq D \leq 2000 \text{ GeV} \\ 2 &\leq \tan \beta \leq 60 \\ \mu < 0 &\quad \text{and} \quad c_{\text{grav}} = 1 . \end{aligned} \quad (7)$$

Regarding the MSSM parameter μ , its magnitude but not the sign is determined by the radiative electroweak symmetry breaking (REWSB). In our model we set $\text{sign}(\mu) = -1$. Finally, we employ the current central value for the top mass, $m_t = 173.3 \text{ GeV}$. Our results are not too sensitive to one or two sigma variation of m_t [21].

It is also well known that weak-scale SUSY can accommodate the $2 - 3 \sigma$ discrepancy between the measurement of muon $g-2$ by the BNL [22] experiment and its value predicted by the SM. It requires the existence of relatively light smuon and gaugino (wino or bino) [23]. BNL has measured an excess of $\sim 3.6 \sigma$ (2.4σ) in muon $g-2$, using $e^+e^- \rightarrow \text{hadrons}$ (hadronically decaying τ) data. Various theoretical computations within the SM [24] have been performed by different groups to explain this excess, but to no avail. The deviation in $g-2$ from the SM prediction is:

$$\Delta a_\mu \equiv a_\mu(\text{exp}) - a_\mu(\text{SM}) = (28.6 \pm 8.0) \times 10^{-10} . \quad (8)$$

In this paper we are looking to the GMSB-Adj parameter space that resolves the $g - 2$ anomaly.

In scanning the parameter space, we employ the Metropolis-Hastings algorithm as described in Ref. [25]. The data points collected all satisfy the requirement of radiative electroweak symmetry breaking (REWSB). We successively apply mass bounds including the Higgs boson [2, 1] and gluino masses [26], and the constraints from the rare decay processes $B_s \rightarrow \mu^+ \mu^-$ [27], $b \rightarrow s \gamma$ [28] and $B_u \rightarrow \tau \nu_\tau$ [29]. The constraints are summarized below in Table 1.

$$\begin{aligned}
123 \text{ GeV} &\leq m_h \leq 127 \text{ GeV} \\
m_{\tilde{g}} &\geq 1.8 \text{ TeV} \\
0.8 \times 10^{-9} &\leq \text{BR}(B_s \rightarrow \mu^+ \mu^-) \leq 6.2 \times 10^{-9} \text{ (} 2\sigma \text{)} \\
2.99 \times 10^{-4} &\leq \text{BR}(b \rightarrow s \gamma) \leq 3.87 \times 10^{-4} \text{ (} 2\sigma \text{)} \\
0.15 &\leq \frac{\text{BR}(B_u \rightarrow \tau \nu_\tau)^{\text{MSSM}}}{\text{BR}(B_u \rightarrow \tau \nu_\tau)^{\text{SM}}} \leq 2.41 \text{ (} 3\sigma \text{)}
\end{aligned}$$

Table 1: Phenomenological constraints implemented in our study.

4 Results

We present our results from the scan we performed over the fundamental parameter space listed in the previous section. We first focus on the regions, which are allowed by the experimental constraints mentioned in the previous section and can solve muon $g - 2$ anomaly. Figure 1 represents our results with the plots in $\Delta a_\mu - M_{\text{mess}}$, $\Delta a_\mu - \Lambda_3$, $\Delta a_\mu - \Lambda_8$, $\Delta a_\mu - D$, $\Delta a_\mu - \tan \beta$, and $\Delta a_\mu - \mu$. All points are consistent with REWSB. Green points are consistent with the experimental constraints including the Higgs boson mass. The yellow points satisfy the muon $g - 2$ constraint given in Eq. (8). The $\Delta a_\mu - M_{\text{mess}}$, M_{mess} plane shows that M_{mess} needs to be larger than about 10^{10} GeV in order to have muon $g - 2$ within 1σ interval from experimental observation. We found that muon $g - 2$ constraint put upper bound for $\Lambda_3 < 10^5$ GeV, see $\Delta a_\mu - \Lambda_3$ plane. Note that we plotted the absolute value of Λ_3 , which is set to be negative in our scan. On the other hand, Λ_8 need to be more than 10^5 GeV in order to accommodate light CP even higgs bound and muon $g - 2$ anomaly. As we mentioned above in order to have experimentally acceptable right handed slepton mass we need to have non zero $U(1)_{B-L}$ D-term. It need to be more than 100 GeV and when $D > 500$ GeV the supersymmetric contribution to muon $g - 2$ anomaly become negligible. The $\Delta a_\mu - \tan \beta$ plane shows that one needs to have $45 < \tan \beta < 55$ in order to satisfy constraint given in Section 3. In the $\Delta a_\mu - \mu$ plane we are shoing solution with relatively small value for $|\mu| < 2.5$. The reason is that we are seeking for the solution when little hierarchy problem is not so severe. As we can see from Figure 1 that there are many solution for $\mu \sim 100$ GeV or so, which means that in the GMSB-Adj scenario we do not have strong fine tuning constraints for electroweak symmetry breaking. We will discuss more about fine tuning and its relation to muon $g - 2$ when we present $\Delta a_\mu - \Delta_{EW}$ plot.

Figure 2 displays our results for the sparticle mass spectrum relevant to the SUSY contributions to muon $g - 2$ with plots in $\Delta a_\mu - m_{\tilde{\chi}_1^0}$, $\Delta a_\mu - m_{\tilde{\chi}_1^\pm}$, $\Delta a_\mu - m_{\tilde{\mu}_L}$, and $\Delta a_\mu - m_{\tilde{\mu}_R}$. The color coding is the same as Figure 1. The lightest neutralino is not heavier than about 200 GeV, and the muon $g - 2$ requirements bounds its mass further at about 50 GeV from below as seen in the $\Delta a_\mu - m_{\tilde{\chi}_1^0}$ plane. A similar result for the chargino

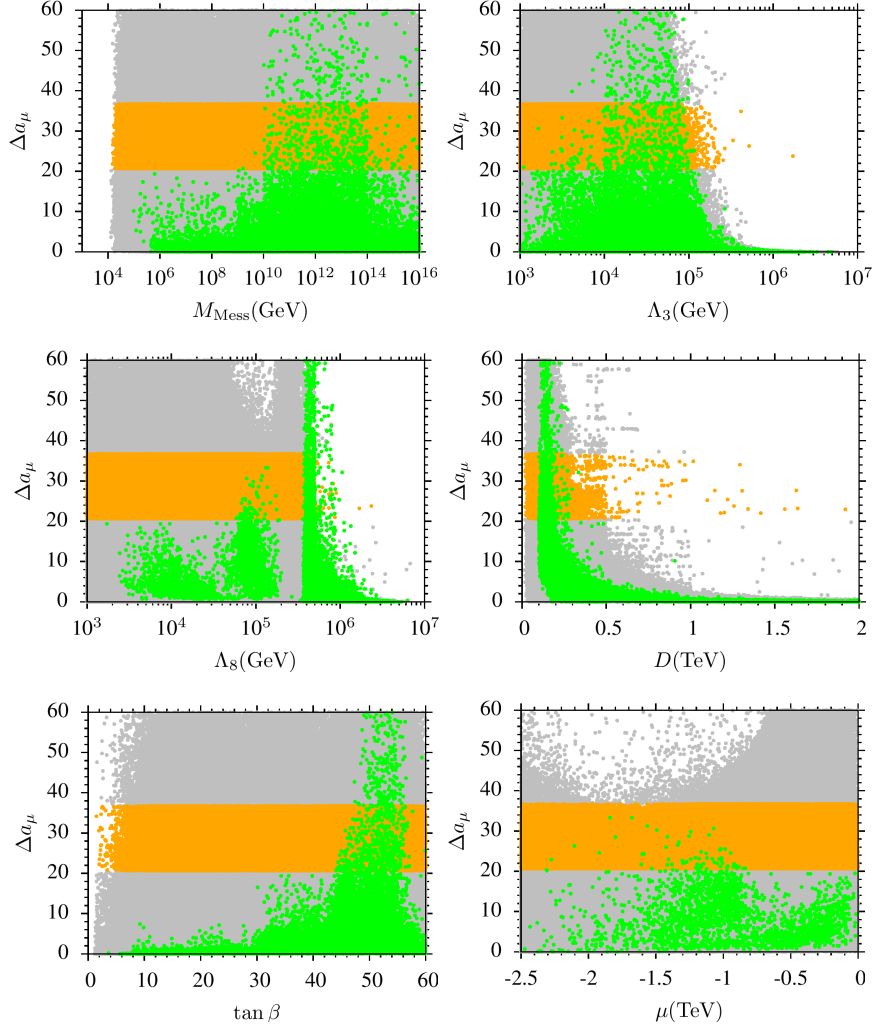


Figure 1: Plots in $\Delta a_\mu - M_{\text{mess}}$, $\Delta a_\mu - \Lambda_3$, $\Delta a_\mu - \Lambda_8$, $\Delta a_\mu - D$, $\Delta a_\mu - \tan \beta$, and $\Delta a_\mu - \mu$. All points are consistent with REWSB. Green points are consistent with the experimental constraints including the Higgs boson mass. The yellow band is an independent subset and it represents regions where Δa_μ would bring theory and experiment to within 1σ .

mass is shown in $\Delta a_\mu - m_{\tilde{\chi}_1^\pm}$. Its mass is required to be lighter than about 800 GeV [31] to have significant contributions to muon $g - 2$. The bottom panels of Figure 2 displays the mass spectrum for both left and right-handed smuons. Since they can have non-zero masses at M_{mess} because of non-zero D-term contributions, they can be as heavy as 2 TeV, and muon $g - 2$ implies $m_{\tilde{\mu}_R} \lesssim 700$ GeV and $m_{\tilde{\mu}_L} \lesssim 900$ GeV.

We continue to present mass spectrum results in Figure 3 with plots in $m_{\tilde{t}_1} - m_{\tilde{\tau}_1}$, $m_{\tilde{q}} - m_{\tilde{g}}$, $m_{\tilde{\mu}_L} - m_{\tilde{\mu}_R}$, and $m_A - \tan \beta$. The color coding is the same as Figure 1 except that yellow points are a subset of green and they represent values of Δa_μ that would bring muon $g - 2$ theoretical and experimental result within 1σ uncertainty. The Higgs boson mass itself requires $m_{\tilde{t}} \gtrsim 2$ TeV (green), and muon $g - 2$ lifts the bound on stops to about 3 TeV (yellow) as seen from the $m_{\tilde{t}_1} - m_{\tilde{\tau}_1}$ plane. In contrast to stops, staus can be as light as about 100 GeV in the same region. The other colored supersymmetric particles are shown in the $m_{\tilde{q}} - m_{\tilde{g}}$, and $m_{\tilde{q}}, m_{\tilde{g}} \gtrsim 4$ TeV. We present the smuon masses once more in the $m_{\tilde{\mu}_L} - m_{\tilde{\mu}_R}$ in comparison to each other. The D-term contribution allows the right-handed

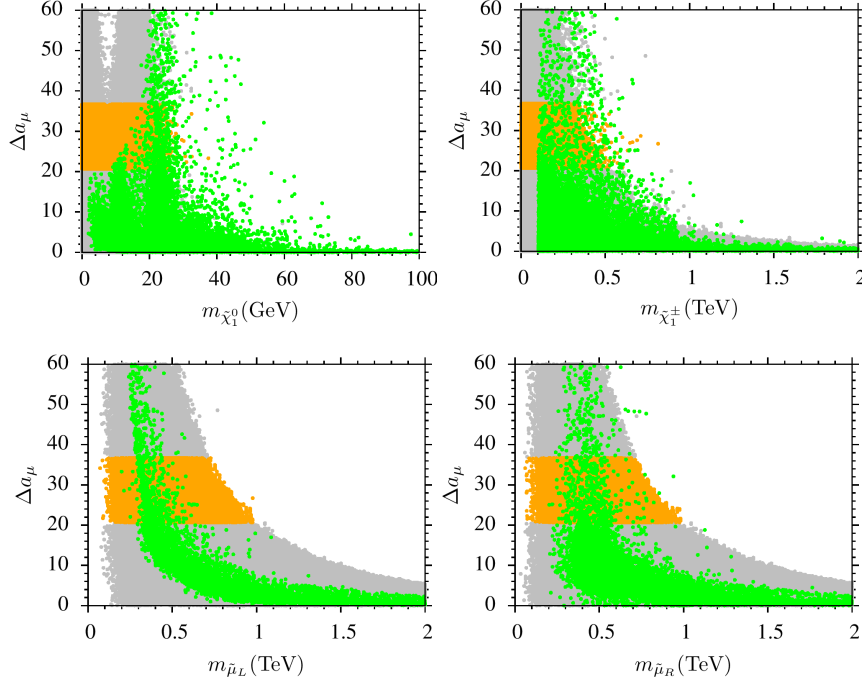


Figure 2: Plots in $\Delta a_\mu - m_{\tilde{\chi}_1^0}$, $\Delta a_\mu - m_{\tilde{\chi}_1^\pm}$, $\Delta a_\mu - m_{\tilde{\mu}_L}$, and $\Delta a_\mu - m_{\tilde{\mu}_R}$. The color coding is the same as Figure 1.

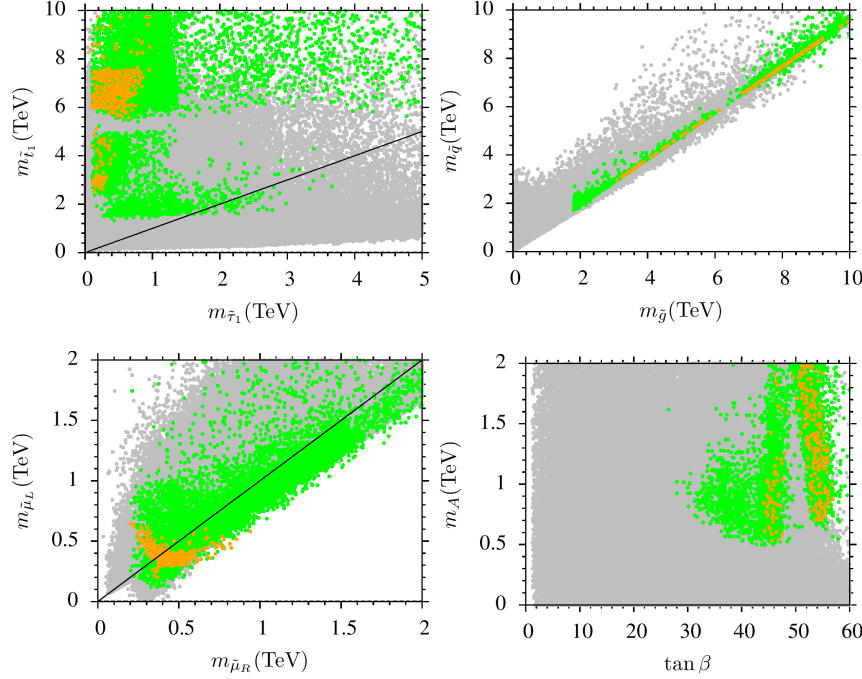


Figure 3: Plots in $m_{\tilde{t}_1} - m_{\tilde{\tau}_1}$, $m_{\tilde{q}} - m_{\tilde{g}}$, $m_{\tilde{\mu}_L} - m_{\tilde{\mu}_R}$, and $m_A - \tan \beta$. The color coding is the same as Figure 1 except that yellow points are a subset of green and they represent values of Δa_μ that would bring theory and experiment to within 1σ .

smuon to be heavier than the left-handed smuon for some solutions (below the diagonal line). Finally, we show the possible mass range for the CP-odd Higgs boson versus $\tan \beta$.

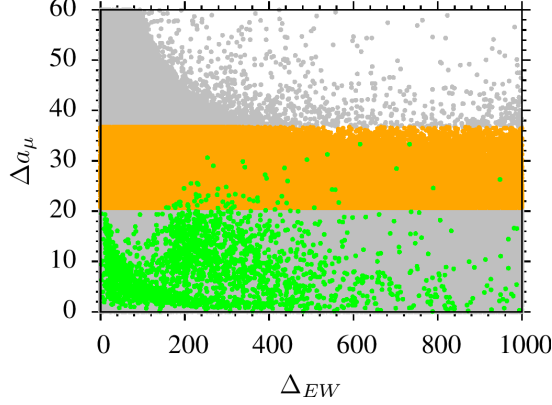


Figure 4: Plot in the $\Delta a_\mu - \Delta_{EW}$ plane. The color coding is the same as Figure 1.

The exclusion limit on CP-odd mass for large $\tan \beta$ can be expressed as $m_A \gtrsim 800$ GeV [30]. Even after the exclusion, there are still plenty of solutions with heavy A -boson, which are hard to be detected at the experiments.

Finally, we discuss the fine-tuning in our model for the cases in which the muon $g - 2$ discrepancy is resolved in Figure 4 with the plot in the $\Delta a_\mu - \Delta_{EW}$ plane. The color coding is the same as Figure 1. For Δ_{EW} = electroweak scale fine tuning parameter calculation we used latest (7.84) version of ISAJET [19]. This calculation includes the one-loop effective potential contributions to the tree level MSSM Higgs potential, the Z boson mass is given by the relation:

$$\frac{M_Z^2}{2} = \frac{(m_{H_d}^2 + \Sigma_d^d) - (m_{H_u}^2 + \Sigma_u^u) \tan^2 \beta}{\tan^2 \beta - 1} - \mu^2. \quad (9)$$

The Σ 's stand for the contributions arising from the one-loop effective potential (for more details see ref. [16]). All parameters in Eq. (9) are defined at the weak scale M_{EW} .

In order to measure the EW scale fine-tuning condition associated with the little hierarchy problem, the following definitions are used [16]:

$$C_{H_d} \equiv |m_{H_d}^2/(\tan^2 \beta - 1)|, \quad C_{H_u} \equiv |-m_{H_u}^2 \tan^2 \beta/(\tan^2 \beta - 1)|, \quad C_\mu \equiv |-\mu^2|, \quad (10)$$

with each $C_{\Sigma_{u,d}^{(i)}}$ less than some characteristic value of order M_Z^2 . Here, i labels the SM and supersymmetric particles that contribute to the one-loop Higgs potential. For the fine-tuning condition we have

$$\Delta_{EW} \equiv \max(C_i)/(M_Z^2/2). \quad (11)$$

Note that Eq. (11) defines the fine-tuning condition at M_{EW} without addressing the question of the origin of the parameters that are involved.

The $\Delta a_\mu - \Delta_{EW}$ plane shows that there is possible to have Δ_{EW} 50 or so. This means that in GMSB-Adj scenario little hierarchy problem can be ameliorated significantly. it was shown in Ref. [32] that the little hierarchy problem can be largely resolved if the ratio between $SU(2)_L$ and $SU(3)_c$ gaugino masses satisfy the asymptotic relation $M_2/M_3 \approx 3$ at the GUT scale, which corresponds to $\Lambda_3/\Lambda_8 > 2$ ratio in GMSB-Adj scenario. We can see from Figure 1 that there are solutions satisfying this condition. In this case the leading contributions to $m_{H_u}^2$ through RGE evolution, which are proportional to M_2 and M_3 , can

cancel each other. This allows for large values of M_2 and M_3 in our scenario while keeping the value of $m_{H_u}^2$ relatively small. On the other hand, large values of M_2 and M_3 yield a heavy stop quark ($> \text{few TeV}$) which is necessary in order to accommodate $m_h \simeq 125 \text{ GeV}$. Since in our scenario bino mass does not depend on Λ_3 and Λ_8 and it is mostly generated through RGE evaluation, it can be around 20 GeV or so, (see Figure 2). Thus, bino loop can be the dominant contributor in muon $g - 2$ calculation. As we can see, requiring to have significant contributions to muon $g - 2$ makes $\Delta_{EW} > 200$, which we consider moderate and quite acceptable under the fine-tuning condition.

Note that in our scenario, Gravitino can be either lightest supersymmetric particle (LSP) or next to lightest supersymmetric particle (NLSP). For a detailed study on these possibilities see in ref. [33]. We will not discuss much about gravitino as the dark matter candidate since there is not much difference here compared to the other GMSB scenario. We only remark that in GMSB-Adj scenario LSP gravitino can be $(O)30 \text{ eV}$, or $(O) \text{ keV}$ or so. Also in our scenario one could invoke axions as cold dark matter and have exactly the same supersymmetric spectrum.

Before concluding our results, we provide a table for three benchmark points exemplifying our results. All masses are in GeV. All points are chosen as to be consistent with the experimental constraints given in Section 3. Point 1 exemplifies a solution with a keV scale gravitino LSP with $\Delta_{EW} \sim 10$, while Point 2 depicts one with neutralino LSP. Both points yield light sleptons ($m_{\tilde{\tau}_1} \sim 193, 176 \text{ GeV}$). Even though the GMSB models typically yield gravitino LSP, GMSB-Adj predicts also neutralino LSP solutions when M_{mess} is large. Point 2 illustrates such a solution with $\Delta_{EW} \sim 200$ despite $M_{\text{mess}} \sim 10^{15} \text{ GeV}$. Point 3 displays a solution which needs, like Point 1, very low fine-tuning ($\Delta_{EW} \sim 10$) at the electroweak scale. In this case, the gravitino LSP is of mass at the order eV. Even though the muon $g - 2$ results of Points 1 and 3 are slightly out of the 1σ band, it is still comparable with the experimental results since $\Delta a_\mu \sim 20 \times 10^{-10}$. Recall that we wrote the absolute value of Λ_3 in Table 2, which is set to be negative in our scans.

5 Conclusion

We explored the sparticle mass spectrum in light of the muon $g - 2$ and the little hierarchy problem in a class of gauge mediated SUSY breaking models in which the messenger fields are resided in the adjoint representation of $SU(3)_C \times SU(2)_L$. To avoid unacceptably light right-handed sleptons we introduce a non-zero $U(1)_{B-L}$ D-term. In this framework, the SSB mass terms for the colored and non-colored sectors are generated different independent parameters, and these two sectors are completely untied, since the hypercharge interactions are absent. These models are also favored by the low fine-tuning requirement in resolution of the little hierarchy problem. We found that cancelations between the terms proportional to Λ_8 and Λ_3 can yield low fine-tuning at any value of M_{mess} .

In addition, a negative Λ_3 along with a negative μ -term allows significant SUSY contributions which accommodate the muon $g - 2$ resolution with the 125 GeV Higgs boson mass. The solutions for the muon $g - 2$ resolution restrict the fundamental parameters as $M_{\text{mess}} \gtrsim 10^8 \text{ GeV}$, and $\Lambda_3 \lesssim 10^5 \text{ GeV}$, while $\tan \beta \gtrsim 35$. The D -term contributions are strictly bounded from above as $D \lesssim 300 \text{ GeV}$, and muon $g - 2$ results sharply drop to about zero for values beyond this bound. In addition the neutralino mass should be lighter than about 30 GeV , while the chargino can be as heavy as about 600 GeV . Smuons also

	Point 1	Point 2	Point 3
Λ_3	0.68×10^4	0.17×10^4	0.20×10^4
Λ_8	0.43×10^4	0.73×10^5	0.47×10^4
M_{mess}	0.29×10^{10}	0.83×10^{15}	0.12×10^7
$\tan \beta$	35	45	36
D	143	100	138
μ	-89	-1028	-69
Δ_{EW}	10	233	10
Δa_μ	20×10^{-10}	26×10^{-10}	20×10^{-10}
m_h	126	125	126
m_H	783	810	678
m_A	778	805	673
m_{H^\pm}	788	817	685
$m_{\tilde{\chi}_{1,2}^0}$	5, 157	10, 799	3, 15
$m_{\tilde{\chi}_{3,4}^0}$	997, 999	2046, 2047	853, 854
$m_{\tilde{\chi}_{1,2}^\pm}$	158, 1000	80, 2047	16, 856
$m_{\tilde{g}}$	1844	3434	1879
$m_{\tilde{u}_{L,R}}$	1758, 1792	3278, 3303	1774, 1800
$m_{\tilde{t}_{1,2}}$	1574, 1657	2823, 2920	1648, 1700
$m_{\tilde{d}_{L,R}}$	1760, 1758	3279, 3290	1776, 1778
$m_{\tilde{b}_{1,2}}$	1606, 1689	2839, 2928	1651, 1731
$m_{\tilde{\nu}_{e,\mu}}$	397	319	284
$m_{\tilde{\nu}_\tau}$	394	408	286
$m_{\tilde{\mu}_{L,R}}$	406, 412	331, 398	297, 312
$m_{\tilde{\tau}_{1,2}}$	312, 467	176, 591	187, 375
$m_{\tilde{G}}$	5×10^{-6}	146	1.36×10^{-6}

Table 2: Benchmark points for exemplifying our results. All masses are in GeV. All points are chosen as to be consistent with the experimental constraints given in Section 3. Point 1 exemplifies a solution with gravitino LSP, while Point 2 depicts one with neutralino LSP. Point 3 displays a solution with a keV scale gravitino LSP with $\Delta_{EW} \sim 10$ and $\Delta a_\mu \sim 20 \times 10^{-10}$.

cannot be heavier than about 600 GeV. On the other hand, the color sector is rather heavy as $m_{\tilde{t}} \gtrsim 2$ TeV and $m_{\tilde{g}} \gtrsim 4$ TeV. The CP-odd higgs mass can be realized in a wide range from about 500 GeV to a few TeV. Despite the heavy spectrum in the colored sector, we have solutions $\Delta_{EW} \approx 10$ satisfying all experimental constraints and makes muon $g - 2$ within 2σ deviation from current experimental bound.

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